Arctic Nearshore Impact Monitoring in Development Area (ANIMIDA) III: Contaminants, Sources, and Bioaccumulation

Technical Summary

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1.1 Overview

The Arctic Nearshore Impact Monitoring in Development Area III (ANIMIDA III) Project was designed to update previous evaluations of impacts that may have resulted from offshore oil and gas exploration and production in the coastal Beaufort Sea. The Bureau of Ocean Energy Management (BOEM), Alaska Outer Continental Shelf (OCS) Region previously sponsored the following three major environmental monitoring programs in the Development Area: (1) the Beaufort Sea Monitoring Program (BSMP, 1984–1989), (2) the ANIMIDA Project (1999–2002), and (3) the continuation of the Arctic Nearshore Impact Monitoring in the Drilling Area (cANIMIDA) Project (2004–2007). As part of this four-year ANIMIDA III, Olgoonik Fairweather (OF), in conjunction with a team of scientists, conducted two seasons of offshore in open water and one season of spring sampling field collection in ice programs. A team of scientists from the University of Alaska-Fairbanks (UAF), The University of Texas at Austin (UTA), Florida Institute of Technology (FIT), Battelle Memorial Institute (Battelle), Kinnetic Laboratories Inc. (KLI), and OF comprise the project team.

Sampling was undertaken during the open-water periods in 2014 and 2015 (late July through early August in both years) and during the 2015 spring-freshet. This report describes observations of (1) physical oceanography, (2) the distributions of trace metals in bottom sediments, suspended sediments, and biota, (3) the characteristics of petroleum hydrocarbons in the sediments and benthic organisms, (4) benthic infauna, carbon resources, and trophic structure, and (5) epibenthic communities and demersal fish communities in the central portion of the U.S. Beaufort Sea.

Most of the metals and hydrocarbons found in sediments and biota from the ANIMIDA III study are introduced naturally by river runoff and coastal erosion (Boehm et al., 2001; Trefry et al., 2003; Rember and Trefry, 2004; Neff et al., 2009; Brown et al., 2010, Ping et al., 2011; Neff and Durell, 2011; Trefry et al., 2013). Very few instances of metal or hydrocarbon contamination have been identified in the coastal Beaufort Sea (e.g., ANIMIIDA III Final Report plus all previous reports and references listed above) because most of the 2.7×10^{12} liters (L, 17 billion barrels) of oil produced in the Alaskan Arctic have been recovered from land or nearshore gravel islands (Alyeska, 2017). When limited instances of contamination have been identified, sources include the following: (1) discharged drilling mud and cuttings within 25-100 meters (m) of exploratory drilling sites (~30 Federal or Federal/State lease sites in the ANIMIDA III study area), (2) activities at coastal locations including West Dock, Endicott, Kaktovik, Northstar, and Liberty, and (3) a few other unidentified sources.

1.2 Field Sampling Summary

1.2.1 2014 Offshore Field Season Summary

The team conducted a 7-day sampling cruise in the Beaufort Sea during August 1-7, 2014. The cruise originally intended to use two vessels, an offshore vessel (R/V *Norseman II*) for water depths between ~ 12-60 m and a nearshore vessel (R/V *Launch 1273*) for water depths less than ~20 m, in the immediate vicinity of the coastline. However, due to mechanical difficulties and foul weather, the nearshore vessel was not able to conduct any sampling this year.

Forty-three stations were originally slated for sampling as per the ANIMIDA sampling plan. Forty-three stations were sampled, in addition to 13 (totaling 56 stations) other secondary and /or opportunistic stations where various samples were collected, depending on the particular discipline (Figure 1). Some of the intended stations were replaced by secondary or opportunistic stations as a result

of challenges experienced with the nearshore vessel. Samples collected include sediment for physical, chemical, and biological analysis, water for physical and chemical analysis, biota for chemical and taxonomic analysis, and water column sensor data for physical oceanographic analysis (e.g., conductivity, temperature, current velocity; an Acoustic Doppler Current Profiler [ADCP] was used only on the offshore vessel).
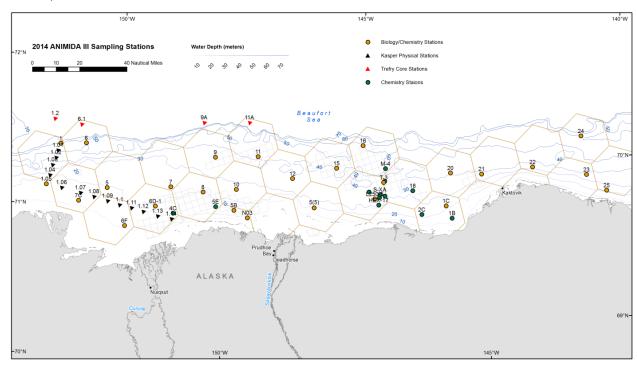

Figure 1. Map indicating ANIMIDA 2014 station locations and type.

1.2.2   2015 Spring Sampling Field Season Summary

A team of scientists from KLI, UAF, and FIT sampled and documented the under ice spreading of the Colville River spring freshet from May 15-29, 2015. The study was designed to delineate and quantify the offshore dispersion of river runoff and suspended sediments during the spring melt as well as trace the dispersion of suspended sediments into deeper, outer shelf water (Figure 2).

The following tasks were completed:

- Collected water samples for dissolved and particulate organic carbon (POC) and metals daily from the Colville River, Kuparuk, and Sagavanirktok Rivers over a ~3-week period starting with the onset of the spring meltwater event; a subset of the samples has been submitted for hydrocarbon analysis. Data for river stage, conductivity, pH, total suspended solids, and other properties were obtained.
- Collected under-ice water samples at multiple stations from 10-12 offshore sites in Harrison Bay.
- Installed temporary moorings for temperature (T) and salinity (S) at as many under-ice locations as possible. Made water velocity measurements utilizing through ice moored ADCPs (4) and point current meters (2).
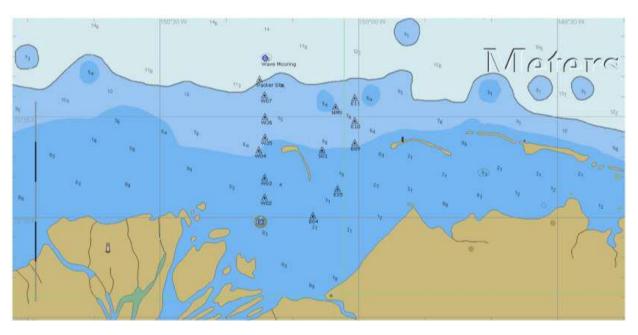
Figure 2. Spring Sampling Through-Ice Locations.

1.2.3   2015 Offshore Field Season Summary

The second and final ANIMIDA III cruise began on July 31, 2015 with the attempted recovery of a physical oceanography mooring and ended on August 8, 2015 with the completion of all sampling activities. Sampling was only conducted from the offshore vessel (R/V *Norseman II*), as the nearshore vessel (R/V *Launch 1273*) not used in 2015.

Stations were selected following numerous team Principle Investigator (PI) discussions and were iteratively modified based on availability and content of historic data at specific locations (e.g., BSMP and Camden Bay stations) as well as extensive expertise of the PIs, study area geospatial spread (east to west across the coastal Beaufort Sea), locations relative to current BOEM lease blocks, and transit timing aspect of the research vessel. The breakdown of the sampling included four main location types: (1) historic BSMP, (2) historic Camden Bay, (3) Random Tessellated (RDW) stations, and new 8 stations from areas identified as lacking in data (Figure 3).
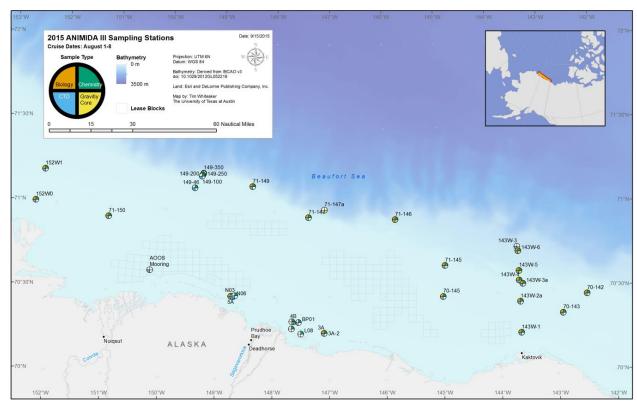
Figure 3. Map indicating ANIMIDA 2015 station locations and type.

1.3   Physical Oceanography

The central and eastern portions of the U.S. Beaufort Sea are essentially estuarine in character and are characterized by the presence of low nutrient, river-influenced water masses at the surface. Nutrient concentrations and salinities increase with increasing distance from the coast and with depth. Temperatures vary with winds and depth; strong stratification can result in surface water temperatures up to 7 °C. The presence of ice that accompanies persistent downwelling favorable winds (winds from the West) generally leads to temperatures <2 °C and the concentration of fresh water against the coast. The trend toward increasing nutrient concentrations with depth and distance from the coast is a result of the influence of shelfbreak water masses. These water masses are advected in an eastward flowing shelfbreak jet, a narrow and swift, bottom intensified current that forms the northern boundary of this shelf. Many of these shelfbreak water masses are derived from Pacific waters which are modified as they flow northward on the Chukchi Sea shelf and eventually form the core of the Beaufort Sea shelfbreak jet. Frequent upwelling favorable winds (winds from the East) in the region reverse the eastward flowing jet and upwell these water masses onto the Beaufort shelf along the bottom. As a result, nutrient concentrations along the outer Beaufort Sea shelf are comparable to values from the northeastern Chukchi Sea shelf. At the surface, the presence of numerous seasonally frozen rivers along the coast means that during the summer, surface waters are typically very fresh with salinities seasonally ranging from 0 to 30. Note, salinity, derived from conductivity is unitless so no units are reported for measured salinities reported herein. Because surface waters can be strongly stratified, temperatures can exceed 6 °C and winds readily move these surface water masses across and along the shelf.

As a result of differences in winds during the two ANIMIDA field seasons, surface water properties and sea ice conditions were very different between years. A moored record of water level (pressure), temperature, and salinity from ~13 m of water, within Harrison Bay, captures the extremes in hydrographic conditions that characterize the shelf, especially the nearshore, where temperatures at the bottom ranged from the freezing point to 5 °C. Salinities at the mooring ranged from 25 to >35. The latter occurred during an episode in mid-winter when brine rejection from freezing was likely taking place near the mooring. Density currents that result from such extreme events are one mechanism nearshore water masses and their dissolved and suspended materials can be transported across the shelf and eventually into the shelfbreak jet. The pressure record from the mooring shows extremes in water levels due to differences in winds: water level deviations of +0.71 m (storm surge due to downwelling favorable winds) and -2.85 m (sea level set down due to upwelling favorable winds) were recorded during the year-long record. In addition to illustrating the strong effect of winds on the shelf, such large fluctuations in sea level mean that low-lying coastal ecosystems, which support numerous bird species, are subject to extremes in conditions, as well. Measurements from the Colville Delta during the spring freshet in 2015 showed that surface waters in the nearshore are essentially fresh (S=0). Thus, conditions in the nearshore are extreme with salinities ranging from 0 to periods of hypersaline water with S>35.

1.4   Trace Metals in Bottom Sediments, Suspended Sediments and Biota

Data for trace metals in bottom sediments, suspended particles, and marine biota were used to identify any recent spatial or temporal changes in concentrations of potentially toxic metals in the coastal Beaufort Sea. Concentrations of 17 trace metals (silver [Ag], arsenic [As], Barium [Ba], beryllium [Be], cadmium [Cd], chromium [Cr], copper [Cu], mercury [Hg], magnesium [Mn], nickel [Ni], lead [Pb], antimony [Sb], selenium [Se], tin [Sn], thallium [Tl], vanadium [V], and zinc [Zn]) in 63 surface sediment and 300 sediment core samples collected during 2014 and 2015 as part of ANIMIDA III were essentially all at natural, baseline values. Previously-established background ratios of metals/aluminum [Al] in sediments were used to identify any sediment metal values that were anomalous. Four anomalies (concentrations above baseline) were observed for Ba and single anomalies were identified for Be, Hg, Sb, V, and Zn during ANIMIDA III. All concentrations of the potentially toxic metals Ag, Cd, Hg, Pb, and Zn were below published sediment quality criteria. At offshore locations (water depths >200 m), concentrations of As, Mn, and Hg were very high in some surface sediments from offshore at water depths of ~200-800 m; these deviations were linked to subsurface, diagenetic remobilization of these metals with subsequent reprecipitation and enrichment in surface sediments. Concentrations of total suspended solids during August 2014 ranged from 0.13-6.1 milligrams per liter (mg/L) and averaged 1.1 mg/L. Particulate Ba/Al ratios in these particles were within 2% of values for bottom sediments and provide a well-defined marker for tracing dispersion of discharged drilling fluids in the water column. In contrast with Ba, particulate iron [Fe]/Al ratios were ~80% greater than in bottom sediments in support of sorption of iron oxides and scavenged metals on suspended particles. Concentrations of the same 19 metals were determined for clams (*Astarte* sp.) and amphipods (*Anonyx* sp.) collected during 2014 and 2015. Results showed a variety of patterns and are presented and discussed here to provide a baseline for future assessments.

1.5   Characteristics of Petroleum Hydrocarbons in the Sediments and Benthic Organisms

Hydrocarbons (polycyclic aromatic hydrocarbons [PAH], saturated hydrocarbons [SHC], and sterane and triterpene [S/T] petroleum biomarkers) were measured in sediment and marine animal

samples collected from the nearshore environment to the continental shelf 50 miles (mi) offshore. Most of the nearshore stations had been sampled in earlier phases of ANIMIDA, and the offshore stations were new. The methods that were used were the same as those used in earlier phases of ANIMIDA.

Though several classes of hydrocarbons were measured, PAH are the class that are of greatest environmental interest. The surface sediment Total PAH concentration generally ranged from 100 to 1,000 nanograms per gram (ng/g), dry weight (d. wt.), and averaged 532 (2014) and 707 (2015) ng/g for the two survey years. These concentrations were comparable to what had been measured in ANIMIDA I and II; the mean concentration for each year in those programs ranged from 380 to 570 ng/g. The hydrocarbon concentrations were also similar to what has been measured in the sediments in other studies in the Beaufort and Chukchi Seas, and other marine regions of Alaska. The surface sediment concentrations were slightly higher at the offshore stations than nearshore, possibly as a result of transport of fine-grained material that tends to have higher hydrocarbon concentrations than coarser material. A sediment core, collected well offshore, had uniform hydrocarbon concentrations at all depths, also in sediments representing deposition from many centuries ago; the amount and source of the hydrocarbons has remained constant for a long time and does not seem to have been altered by human activities. The hydrocarbons in the Beaufort Sea sediments are primarily from non-oil petrogenic and biogenic sources, with small amounts of pyrogenic hydrocarbons. Most of the hydrocarbons are carried to the Beaufort Sea through coastal erosion and river input of hydrocarbon rich materials, such as peat and shale. The concentrations of PAH in the sediments are low, at natural background levels, below concentrations that could cause harm to marine animals.

The concentrations of PAH, and other hydrocarbons, were more variable in the tissue of marine animals than in the sediment; there are seasonal and annual fluctuations with aspects of the animal's life and feeding. The mean Total PAH concentration ranged from 25 to 30 ng/g, d. wt., in the amphipods collected in 2014 and 2015, from 44 to 380 ng/g in the clams (a few values above 100 ng/g were attributed to analytical challenges, and do not represent actual field concentrations), and from 24 to 94 ng/g in the Arctic cod. The concentrations did not correlate well with the lipid content of the animals, demonstrating that many factors influence the accumulation of hydrocarbons by marine animals. There was no clear geographic pattern in the hydrocarbon concentrations of these marine animals. The tissue hydrocarbon concentrations were comparable to what had been measured during ANIMIDA I and II, and in other studies in the Arctic. The concentrations of the PAH that have accumulated in the marine animals are low, at natural background levels, and well below concentrations that could cause toxic effects or other harm to those animals.

1.6   Benthic Infauna, Carbon Resources, and Trophic Structure

A quantitative assessment of the biomass, abundance, and community structure of benthic populations of the Beaufort Sea Shelf along with a detailed characterization of food web dynamics were carried out as part of ANIMIDA III. Our analysis documented a benthic species inventory of 353 taxa collected from 126 individual van Veen grab samples (0.1 meters squared [m^2]) at 42 stations. Infaunal abundance was dominated by polychaetes, bivalves, and amphipods; bivalves, echinoderms, and polychaetes constituted the greatest fractions by biomass. Shannon Diversity Index values of the infaunal community at different stations (by abundance) was between 1.5 and 4.1 (mean = 3.3 ± standard deviation [SD] 0.02), out of a possible range of 0-5. Thirty of the 42 stations had high diversity values, between 3.1 and 3.9, and two stations had higher values, 4.0 and 4.1. Pielou's Evenness Index values ranged from 0.86

to 0.98 (mean = 0.96 ± SD 0.52) out of a range of 0-1, demonstrating balanced contributions from all collected species at many but not all stations.

We used a Biota and Environment matching routine to examine the relationships between infaunal distributions of all collected taxa with the physical environment. A combination of water depth, TOC, and salinity correlated with infaunal abundance distribution (ρ = 0.54). We also noted that stations exhibiting the highest levels of both pyropheophorbide and pheophorbide *a* (chlorophyll degradation products that are markers for metazoan grazing) were characterized by the highest infaunal abundance. These stations contained polychaetes and crustaceans that constituted >75% of all organisms present and were located in three "hotspots" along the Beaufort shelf. The three hotspots include mid-shelf locations in the western Beaufort in Harrison Bay, the central Beaufort, including Stefansson Sound, and the eastern Beaufort from Barter Island east to Icy Reef. Our results imply a strong correlation between infaunal abundance and a deposited sediment pool that may include ice algae, bacteria, and other benthic microalgae. Preliminary data on the stable nitrogen isotopic composition of benthic organisms reveal complex food webs dominated by decidedly omnivorous consumers that occupy up to four trophic levels. Stable carbon isotopic composition of these benthic organisms, along with isotopic analyses of suspended particulate organic matter (SPOM) and zooplankton, reveal a primary mixture of terrestrial and phytoplankton carbon, but an additional benthic microalgal subsidy appears to play a role at moderate depths that correspond to the three hotspots of infaunal abundance. Half the genera examined also displayed a distinct eastward depletion in δ^{13}C values that likely reflects the influence of the Mackenzie and other sources of freshwater runoff in the Eastern U.S. Beaufort Sea, which transport allochthonous inputs of terrestrial organic carbon that become available as a food source to the benthos. These results provide compelling evidence for the important role of terrestrial carbon in Beaufort Sea food webs. Aside from the nearshore Sagavanirktok and Colville Rivers' deltas, the U.S. Beaufort Sea shelf overall supports a rich benthic infauna community, particularly in the region around Kaktovik, where repeated upwelling events have been reported.

1.7   Epibenthic Communities and Demersal Fish Communities

The dynamic physical and biological gradients of the Beaufort Sea shelf have a distinctive influence on epibenthic and demersal fish standing stocks. Epibenthos and demersal fish community structure vary both along and across shelf. Epifaunal communities shallower than approximately 20 m, sampled primarily in the western part of the study area near the Colville and Sagavanirktok Rivers, were relatively depauperate in species richness and abundance and biomass, likely related to a combination of bottom fast ice, scour by deep-draft ice, and extreme salinity changes during spring break-up. Dominant epibenthos in this zone included mobile crustaceans. Shelf areas outside such chronic perturbations were more species rich with largely overlapping character species in several community clusters. Shelf break and upper slope fauna formed distinct clusters, with typical deep-water species were only found at the deepest stations. Dominant fauna on the shelf and upper slope included echinoderms and mollusks. While demersal fish were less abundant and diverse than epibenthic invertebrates, fish communities were also distinct between nearshore and offshore areas, though less bound to the 20 m isobath and grouped in fewer clusters. Sculpins (*Cottidae*) generally dominated by abundance; while snail fishes (*Liparidae*), cods (*Gadidae*)*,* and eel pouts (*Zoarcidae*) also contributed almost equally to the species inventory. Along the shelf, the decreasing influence of Pacific-origin water along the continental slope resulted in lower epibenthic stocks east of approximately 150° W compared to previous studies conducted further west. A shift in taxonomic composition also aligned with this longitude.

In summary, the ANIMIDA III results document that epibenthic communities reflected the physically very dynamic nature of the Beaufort Sea shelf, characterized by strong land-ocean interactions in its nearshore zone, and its interaction across a steep slope that reaches into Atlantic-origin waters. The areas off the Colville and Sagavanirktok Rivers contained less rich epibenthic communities than the Chukchi-influenced western Beaufort Sea and also somewhat less rich communities than the shelf region off Barter Island.

1.8 References

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